# Mutual Peer Tutoring: A Collaborative Addition to the Cognitive Tutor: Algebra-1

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**Abstract**. Although the Cognitive Tutor: Algebra-1 is effective at increasing individual learning, it lacks support for collaboration between students. We intend to explore the potential benefits of integrating a mutual peer tutoring script with the cognitive tutors, such that students take turns tutoring each other on problem-solving tasks, rather than being tutored directly by the computer. The script is based on current Algebra-1 curriculum goals and situated within the cognitive tutor environment, but requires collaborative additions to the interface and cognitive model. We expect that the script, in conjunction with the cognitive tutors, will improve domain learning and knowledge of problem-solving skills.

## Introduction

A cognitive tutor is an intelligent tutor that compares student action during problem-solving to a model of correct action, and provides context-sensitive hints, error feedback, and problem selection. These tutors are effective at increasing student learning; use of the Cognitive Tutor: Algebra-1 (CT) has been shown to improve algebra understanding by about one standard deviation over traditional classroom instruction [1]. Because students would show further learning gains if their use of the cognitive tutors was balanced with collaborative activities, the CT is intended to be deployed in classrooms where students work together in groups and teachers act as facilitators, not lecturers. Unfortunately, this collaborative vision is not always realized in practice [2].

Collaboration can increase student mastery of domain knowledge and reasoning strategies, but is only effective when designed to encourage particular behaviours, such as providing group members with useful help, resources, and feedback [3]. To this end, many researchers develop collaboration scripts, or structured interactions with designated roles and activities for participating students. These scripts engage students in elaborate cognitive activities that promote domain learning [4], and might be a way of introducing collaboration into the CT environment.

One type of collaboration script is a mutual peer tutoring script. In mutual peer tutoring, a student first tutors a partner and then is tutored by the same partner. To be most effective, tutoring sessions need to be structured and incorporate rewards for good performance [5]. Tutors must prepare ahead of time [6] and, during the tutoring session, provide elaborated explanations [7] that the tutee can constructively use to solve the problem [8]. Making individual students aware of and accountable for the skills that they are acquiring has been shown to increase learning in peer tutoring settings [9]. In general, incorporating these elements into a peer tutoring script tends to increase student learning.

We propose to integrate collaboration into the existing cognitive tutor framework using a peer tutoring script (PTS) that is consistent with the curriculum goals of the CT [10]. The script will be easy for students to use, because it will be built upon the existing CT interface. Students will already be aware of tutoring concepts, because they will have internalized information about the tutoring process due to their previous exposure to cognitive tutors [11]. Finally, this integration will leverage the modeling capabilities of the CT to build a cognitive model of the student collaboration that can further support a positive interaction.

In this paper, I review the structure of the current CT. Next, I describe the script, and detail additions to the CT in terms of the interface and cognitive model. We expect that the integration of the peer tutoring script and CT will increase student algebra achievement.

## 1. Cognitive Tutor: Algebra-1

The CT focuses on “the mathematical analysis of real world situations and the use of computational tools” [1]. Students read a word problem and related mathematical questions in the Scenario Window (Figure 1). To solve the problem, students can use the Worksheet, Grapher, and/or Solver Windows. In the Worksheet, students identify quantities and units, answer Scenario questions, and enter algebraic expressions. The Grapher is for labelling axes, setting axes bounds, and plotting lines and intersection points. Students use the Solver to solve equations in a step-by-step fashion. Once students have completed all problem steps, they select “Done” from a menu, and proceed to the next problem.

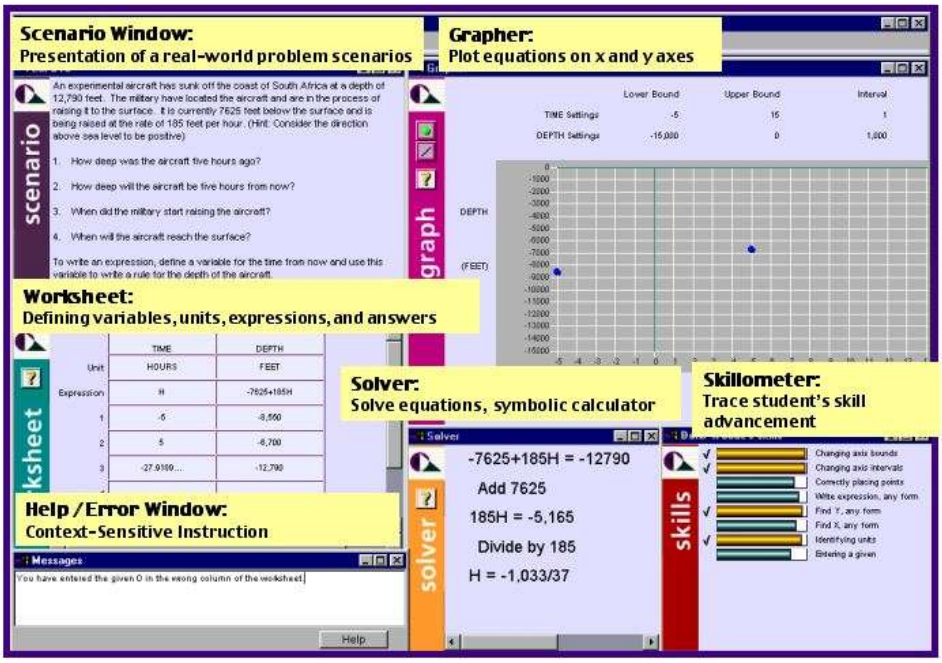


**Figure 1**. A screenshot of the Algebra Cognitive Tutor

As the student works on the problem, the cognitive tutor performs model tracing, monitoring the student’s progress based on a model of correct and buggy (incorrect) student performance. When the student makes an error, the cognitive tutor will immediately “flag” it (i.e., turn input text red) and, for common errors, output a message in the Help/Error Window that explains the student’s misconception. At any time, the student can request help, and the cognitive tutor will provide hint messages in the Help/Error Window. For each desirable action in the cognitive model, there are hint messages at multiple levels, so if students cannot solve a problem using the first hint, they can request the next hint. Model tracing insures that students get immediate and useful feedback on their progress.

The tutor also performs knowledge tracing [12] by keeping a running estimate of student mastery of skills and areas of difficulty. Skill levels are displayed in the Skillometer window, shown in the lower right of Figure 1, so that students are aware of their progress. Once a skill bar crosses a particular threshold, it is marked as a known skill. Cognitive tutors choose problems in a unit based on the skills the student has not yet mastered.

## 2. Expanding the Cognitive Tutor Curriculum using the Peer Tutoring Script

The PTS builds on the existing algebra problems and tools in the CT curriculum. Students are placed in homogeneous dyads with respect to age and gender and take turns being the peer tutor (the person doing the tutoring) and the peer tutee (the person being tutored). In the first phase of the script (or *preparation phase*) peer tutors perform exercises related to each problem they will be helping the peer tutees solve in the second phase (the *collaboration phase*). During the final phase (the *meta-evaluation phase*), the students have a structured discussion of the skills they used. Students should show learning gains after using this script because of its peer tutoring and monitoring requirements.

In the *preparation phase,* the peer tutor prepares to teach the peer tutee. Peer tutors read through an example solution for the current problem and solve an analogous problem. They then reflect on their role as a tutor by matching the skills required to solve the problem with the steps taken, rating the difficulty of the skills, and thinking about how they would explain the problem steps. For example, the peer tutor might be given the scenario and solution to this rate-of-change story problem found in the CT curriculum: "A huge mirror with a telescope is being moved by truck from Pittsburgh, PA to Charleston, South Carolina, a distance of 523 miles. The truck averages 12 miles per hour and has already traveled 70 miles." After reading through the example solution, involving the use of the Worksheet and Grapher, students would be asked to solve a similar problem with different surface features (i.e., 12 miles per hour might become 17 miles per hour). Students would then explictly match problem-solving skill questions, such as "Can you find an expression for the problem?" to steps they have taken in solving the problem, such as typing "y = 12x + 70" in the appropriate textfield in the Worksheet. Students might rate finding the expression as a difficult skill, and, to further prepare for the tutoring, explain to themselves the steps they took in finding the expression. Throughout this process, the students will be aided by the CT, which will offer hints and bug messages as necessary.

In the *collaboration phase*, the peer tutor helps the peer tutee solve the problems that the tutor completed in the preparation phase. As in the individual use of the CT, the peer tutee is given the problem in the Scenario window, and solves it using the relevant tools (in the above example, the Worksheet and the Grapher). However, it is the peer tutor who is responsible both for providing explanations to the tutee and for rating the tutee's mastery of the skill questions. For example, the first step in solving the problem might be identifying the quantities involved. As the peer tutee correctly completes this step by filling in the quantity names in the worksheet, the peer tutor would increase the values of the skill bar in the Skillometer beside the skill question "Can you identify the quantities involved in the problem?" The next step might be identifying the units involved in the problem. If the peer tutee gets this step wrong, the peer tutor is expected to recognize that the tutee needs help, explain what to do, and then confirm that the tutee understands the explanation. The peer tutor will be encouraged to formulate good explanations by first asking a leading question, then providing a hint, and then providing a more detailed description of how to solve the problem. This rating and hinting process continues until the problem is complete. The CT will also be used during this phase to monitor and tutor the collaboration between the students, ensuring that the dyads solve the problem correctly and provide each other with good explanations and feedback.

In the *meta-evaluation phase*, the students have a structured discussion about the skills involved in the problems. The peer tutee asks the peer tutor each skill question, the peer tutor explains how to complete the skill, and the two students discuss the merits of the peer tutor's answer. Next, the peer tutee looks at his or her rating on that skill, explains the mistakes made, and discusses whether the rating is justified. The students also examine the preparation to teach that skill, reflecting on simple questions such as, "Did the peer tutor think it would be difficult?" Eventually, the students will come to an agreement on how to answer the skill question, the peer tutee will input the answer, and the students will move on to the next skill. The purpose of this phase is to have the students reflect very specifically on the steps they took and skills they employed in solving the problems.

Learning gains due to this approach are expected to come from student engagement in positive collaborative behaviors and skill-monitoring. The preparation phase should allow the peer tutor to master a given set of problems, even if the student has been previously unsuccessful at math. The skill reflection exercise should lead peer tutors to think in elaborated ways about the problem, encouraging them to link concrete problem-solving steps to abstract skills and describe how they would explain those steps. During the collaboration phase, the tutor's explanations should benefit both students. Because the tutor's explanations have been prepared, even weaker students should serve as effective tutors, and tutees of all abilities should be able to use the explanations constructively. The process of rating the tutee should help both peer tutors, who will become more aware of the skills involved in solving the problem, and peer tutees, who will become more aware of their progress. The meta-evaluation phase is expected to be useful because students will discuss the problem steps and skills employed in the previous two phases in further depth. If the problem is challenging enough, these benefits should appear in dyads of all abilities.

## 3. Integrating the Peer Tutoring Script with the Cognitive Tutor: Algebra-1

To implement the PTS, collaborative additions need to be made to the CT. Because it is important that the PTS is situated within the CT environment, the script uses preexisting elements of the CT, such as the Worksheet, Grapher, and Solver tools. Some changes involve adding additional tasks to the interface and model, such as the skill reflection task in the preparation phase. These changes are relatively simple to implement. However, the collaborative extensions are more complex and require more description.

### *3.1 Interface Changes for Collaboration*

The primary change to the structure of the CT occurs during the collaboration phase, because collaboration is not supported in the current interface. In the collaboration phase, students are located at different computer terminals. Students share windows so that an action performed by one student is seen by the other student. Some shared windows allow some actions from one student and different actions from another student. Table 1 contains a list of the windows that will be available in the collaboration phase, their visibility to each student, the actions they allow, and their use.

Despite these necessary changes, the use of the interface in the collaborative phase will be similar to students' experiences during the individual use of the cognitive tutors. The only new window is a Chat Window, which allows the students to discuss the problem. Further, the actions that the peer tutor can perform in this phase parallel the cognitive tutor actions in the individual use of the tutor: flagging errors, updating the Skillometer, and providing feedback in the Chat Window. Student familiarity with the individual tutors should generalize to their use of the collaborative tutors.

**Table 1**. Interface Windows in the Collaboration Phase

| Interface Tool | Shared | Allowed Actions | Use |
|---|---|---|---|
| Scenario Window | Yes | None | Problem description |
| Completed Tools from Preparation Phase | No - visible only to the peer tutor | None | Answers to the problem |
| Active Tools | Yes | Peer Tutor – flag actions<br>Peer Tutee – input actions | Tools the peer tutor must use to solve the problem |
| Chat Window | Yes | Text input | Place for Peer Tutor to give hints and feedback |
| Skillometer | Yes | Peer Tutor – changing the values of the skill bars | Facilitates student monitoring of skills |
| Hint/Error Window | No - each student has a separate window | None | Place for Cognitive Tutor to give hints and feedback |

### *3.2 Developing a Cognitive Model for Collaboration*

Adding collaboration to the cognitive model is another change to the CT. Because the two students are at different computer terminals, the CT can "model trace" *each* student's collaborative actions and provide feedback as necessary. By improving the interaction between the students, the CT will increase learning gains. To achieve this difficult goal, a model will be developed for peer tutoring, using empirical data from student collaboration.

In an early step toward developing the cognitive model, we conducted a pen-and-paper pretest of the PTS with two dyads of middle-school students. As we expected, the process of the tutoring needs to be supported. Peer tutors went through a process of watching the tutee solve each problem step, comparing the solution to their answers, and then rating the student on that particular skill. When they had to provide explanations to the tutee, they went through three steps: recognizing that the student needed help, providing explanations, and then confirming that the student understood. Should future studies support these observations, a cognitive model can be developed that emphasizes these tutoring stages.

Surprisingly, tutors made specific errors that suggest that the content of the tutoring sessions also needs to be modeled. There were skills for which the peer tutors wanted to provide explanations, such as writing an algebraic expression, but were unsure of how to proceed. They would fail to explain problem steps in a manner that their tutee could understand, or would provide the tutee with too much information. On a parallel note, peer tutees did not always use the tutor's explanations constructively, copying down the answer without ensuring that they understood the material. Using this and further pretest data, it is possible to gather information about common student errors within the context of the PTS that can form the basis for definitions of buggy student actions. Although the development of a cognitive model for tutoring is difficult, we think the initial step of creating a model for the tutoring process in the PTS is achievable. Once that is accomplished, a model for the tutoring content can be considered.

## 4. Future Work

Although the CT has been effective at increasing student learning, it lacks support for collaboration, which has also been shown to be beneficial. We have proposed to add collaborative features to the existing CT curriculum, expanding the interface and cognitive model, by incorporating a mutual peer tutoring script. This script builds on students' experience with the CT by putting students in the role of the computer, asking them to “model trace” their tutee's steps, provide feedback as necessary, and update their estimates of the tutee's mastery of the skills. We anticipate that these additions will improve students' domain-content understanding and knowledge of desired domain skills, by increasing their ability to provide useful explanations and to monitor their own and others’ performance.

The addition of the PTS to the CT involves design and implementation phases, followed by an experimental phase to evaluate the suitability of the script for deployment. We will be pretesting the PTS using dyads of middle school students to refine the script and aid in the design of the collaborative interface and cognitive model. Simultaneously, we will be implementing the changes to the CT and developing appropriate algebra problems to complement the script. In the fall, we will be conducting classroom studies with the modified CT and evaluating the effectiveness of the PTS. The combination of collaboration and cognitive tutor methodology should combine the benefits of both approaches.

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